EXHIBIT A

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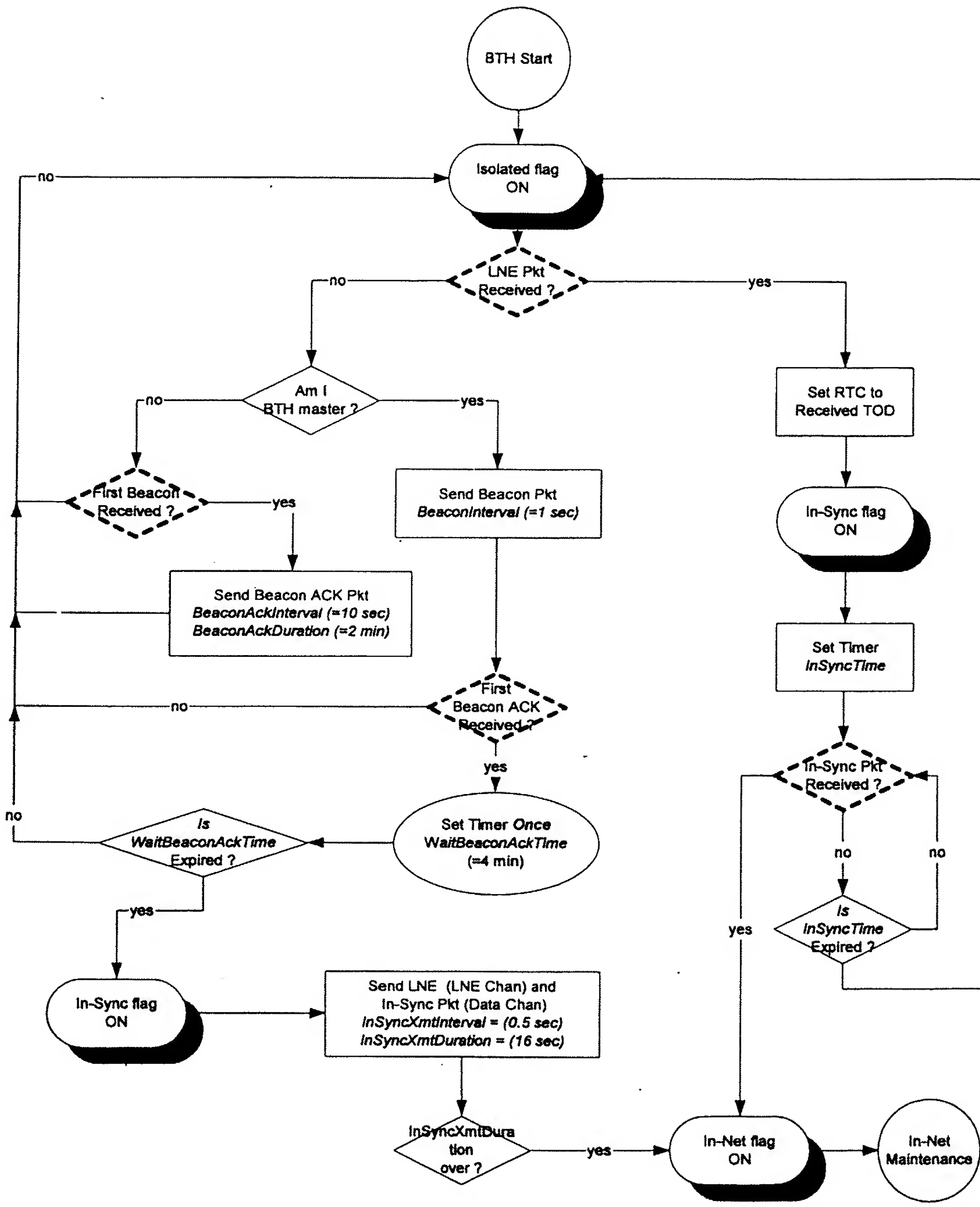

Type 1 = Beacon (LNE Chan) Type 2 = LNE (LNE Chan) Type 3 = In-Sync (Data Chan) Type 4 = In-Net (Data Chan)	Local GPS	BTH	CH or CM	CS Beacon	BDE Bit = 1 Beacon BDE Bit = 0 Beacon ACK	# GPS Hops

BTH pre-defines a node

- Any member can be BTH master clock after predefined period !!!

Aso

GPS based → BTH based in Twait expired!

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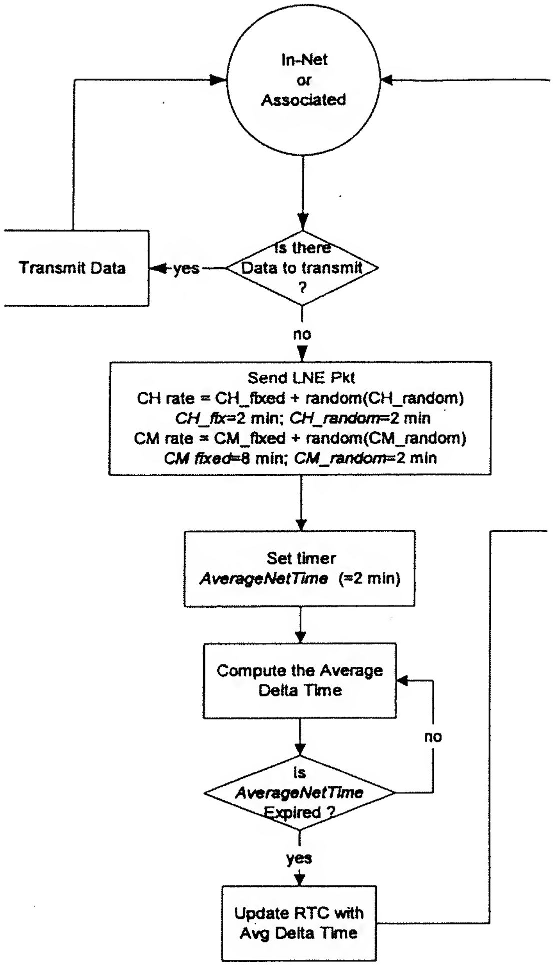
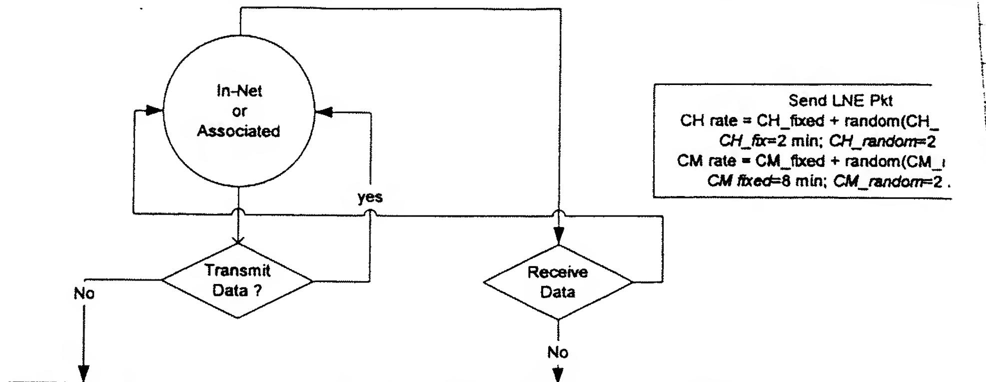




LNE XMT Rate

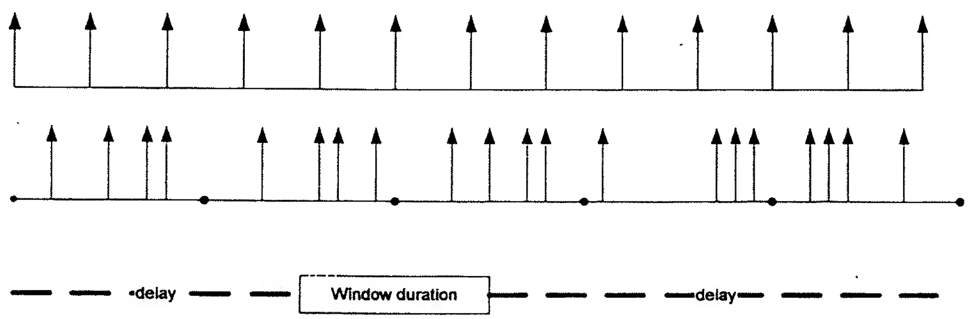
Size	CM rate	CH rate
10%	10sec	4sec
20%	10sec	4sec
30%	15sec	5sec
40%	15sec	5sec
50%	20sec	6sec
60%	30sec	6sec
>70%	40sec	6sec

formula 1

Search Period for LNE Pkt

Size	Search Start	Window
10%	0 min + modulo 5 + ran(30 sec)	18 sec
20%	1 min + modulo 5 + ran(30 sec)	18 sec
30%	2 min + modulo 5 + ran(30 sec)	18 sec
40%	3 min + modulo 5 + ran(30 sec)	18 sec
50%	4 min + modulo 10 + ran(30 sec)	12 sec
60%	-1 min + modulo 10 + ran(30 sec)	12 sec
>70%	-.5 min + modulo 10 + ran(30 sec)	12 sec

formula 2



Question:

- Why is CH rate higher than CM ?
- Why is LNE transmit rate too fast ?
- Can IDR allow the LNE window size of 12 and 18 seconds ?
- How do the receiver open the window if data is receving ?
- What does the receiver solve this conflict bewteen data and LNE ?
- **MergeInProcess_flag ON: Stop the LNE search window operation**

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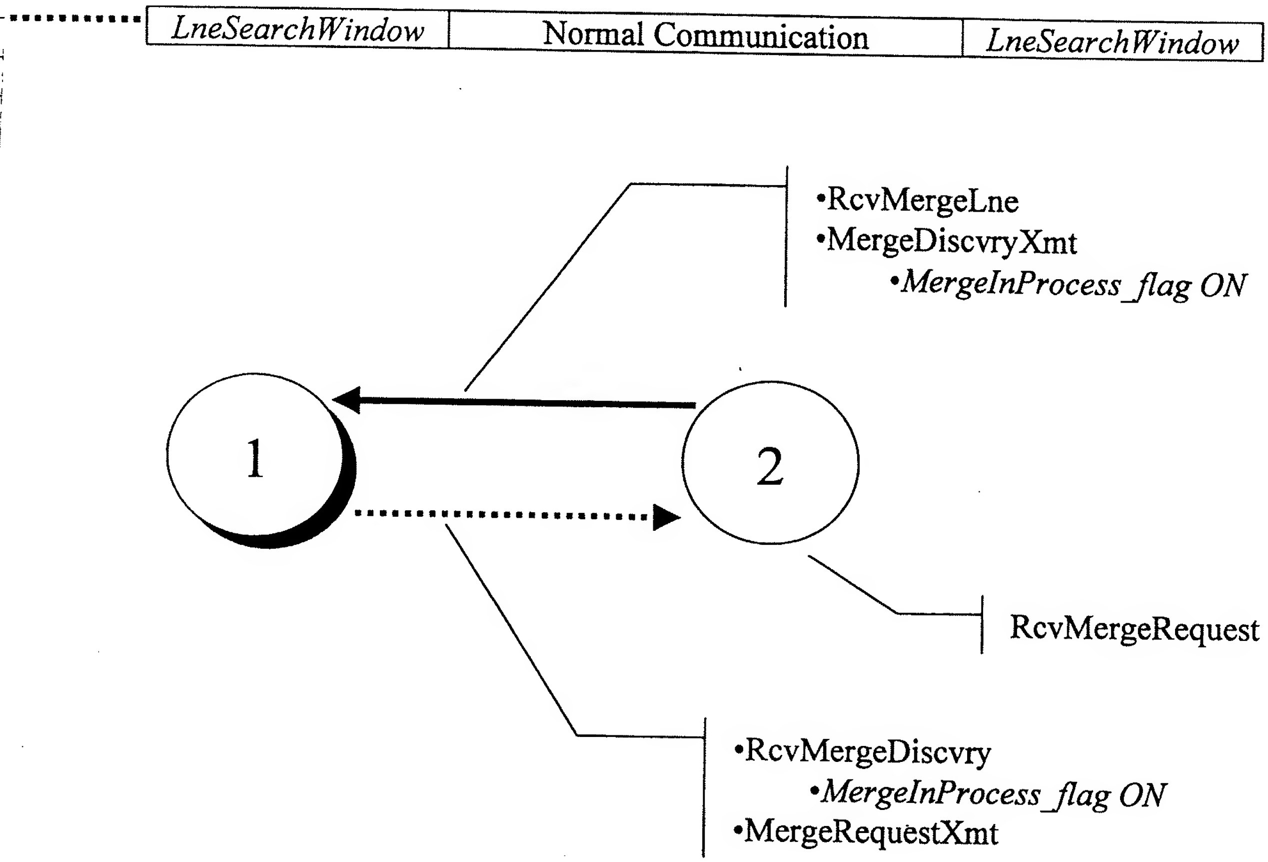

- MergeInProgress_flag terminate Lne Search window Op
- Because T/R configuration, the efficient usage of Receiv for Lne Search and Normal data is "the crucial".
- As soon As the Merge PKT is received, the set this flag to stop the LneSearch and ready to receive the Normal data.

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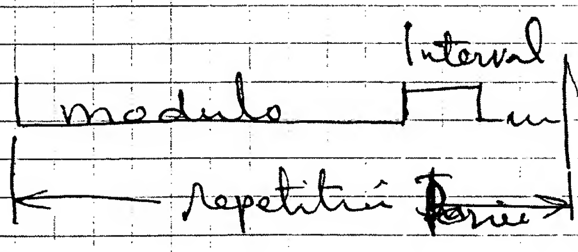
```
TodFilter(LneSearchWindow):Node = 2 Node_nbr = 3 nNumRcvdLneWindow = 4 LocalCloc
kTime_nbr_rcv = 41.900051
        LneWindowStartTime_ptr = 40.091818 LneWindowStopTime_ptr = 43.091818

RcvMergeLne:    Node=2 Nbr=3 TOD=2 MGE=0 Epoch=398 RealTime=37.326493 LocalTime=
39.936472 dDelta=-2.609979

MergeDiscvryXmt:        Node=2 Nbr=3 TOD=2 MGE=1 Epoch=399 RealTime=37.390021 Lo
calTime=40.000000 dDelta=-2.609979

TodFilter(RcvData):Node = 1 Nbr = 2 LocalClockTime_nbr_rcv = 40.004785 mergeInPr
ocess_flag = 0, MsgType = 5

RcvMergeDiscvry:        Node=1 Nbr=2 TOD=2 MGE=1 Epoch=400 RealTime=37.394806 Lo
calTime=40.004800 dDelta=-2.609994

TodFilter(OutOfEpoch):Node = 1 Nbr = 3 NumDropEpochWindow = 18 LocalClockTime_nb
r_rcv = 42.009520
        dEpochStartTime = 40.000000 EpochStopTime = 40.100000 mergeInProcess_fla
g = 1
TodFilter(OutOfEpoch):Node = 2 Nbr = 3 NumDropEpochWindow = 17 LocalClockTime_nb
r_rcv = 42.009526
        dEpochStartTime = 40.000000 EpochStopTime = 40.100000 mergeInProcess_fla
g = 1

MergeRequestXmt:        Node=1 Nbr=2 TOD=2 MGE=1 Epoch=401 RealTime=37.490005 Lo
calTime=40.100000 dDelta=-2.609995

TodFilter(RcvData):Node = 2 Nbr = 1 LocalClockTime_nbr_rcv = 40.104785 mergeInPr
ocess_flag = 1, MsgType = 6

RcvMergeRequest:        Node=2 Nbr=1 TOD=2 MGE=1 Epoch=400 RealTime=37.494790 Lo
calTime=40.104769 dDelta=-2.609978
        dWaitToAutoMergeNetTime = 5.000000 dAutoMergeStartTime = 45.104769
```

Formula 1 : LneXmt~~Rate~~ total_~~network~~ nbr_network

Formula 2 :



Prob{at least 1 Lne pkt arrival} = $1 - e^{-2\lambda\tau}$ (ALOHA)

λ = (LneXmtRate_total_nbr_network) * $\frac{\text{Interval}}{\text{Repetition Period}}$

τ = Interval

∴ Prob{at least 1 pkt arrival} $\triangleq P_s = 1 - e^{-2\lambda\tau}$

SIGNED BY CJ Yoon DATE Sept 5 '02

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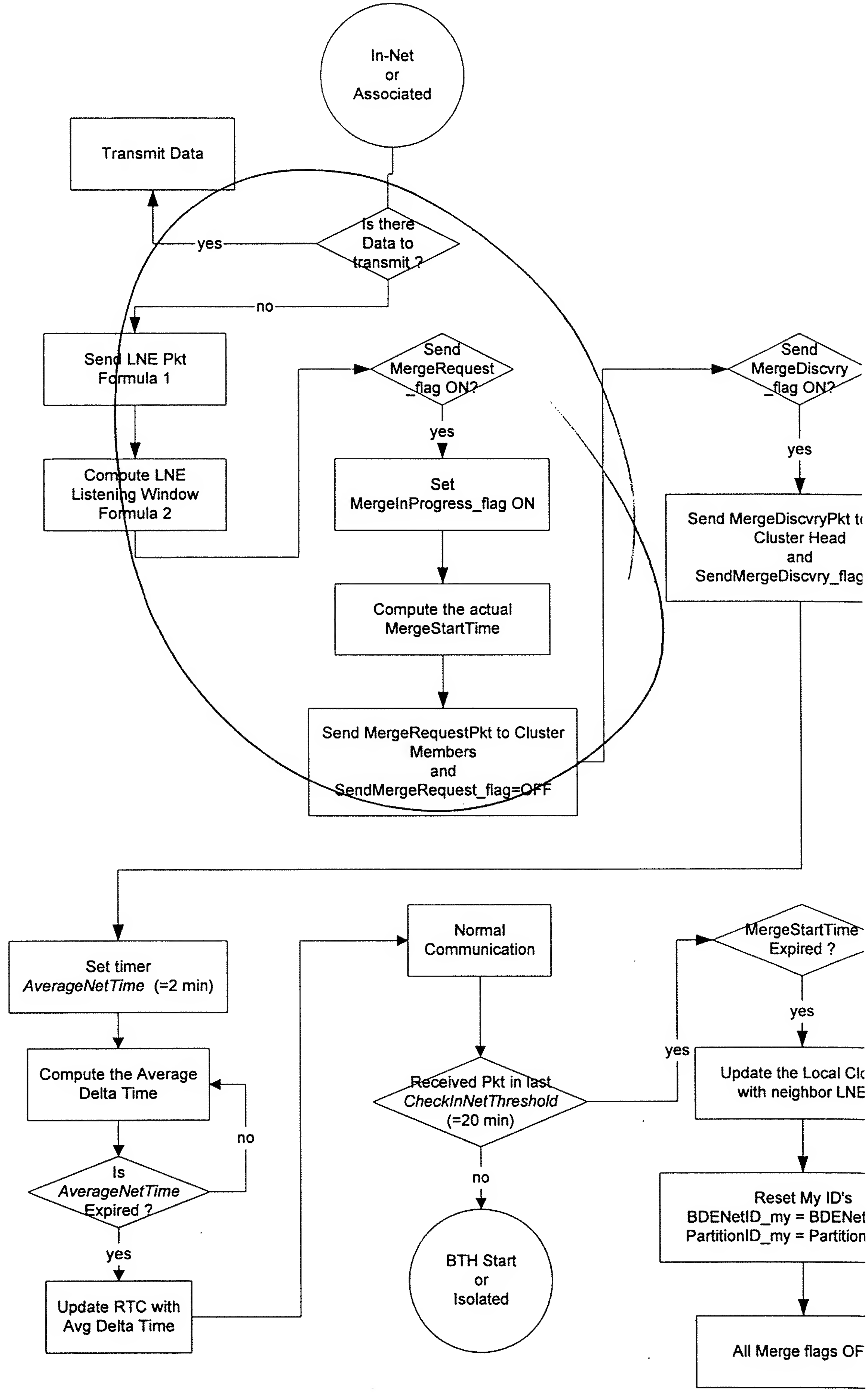

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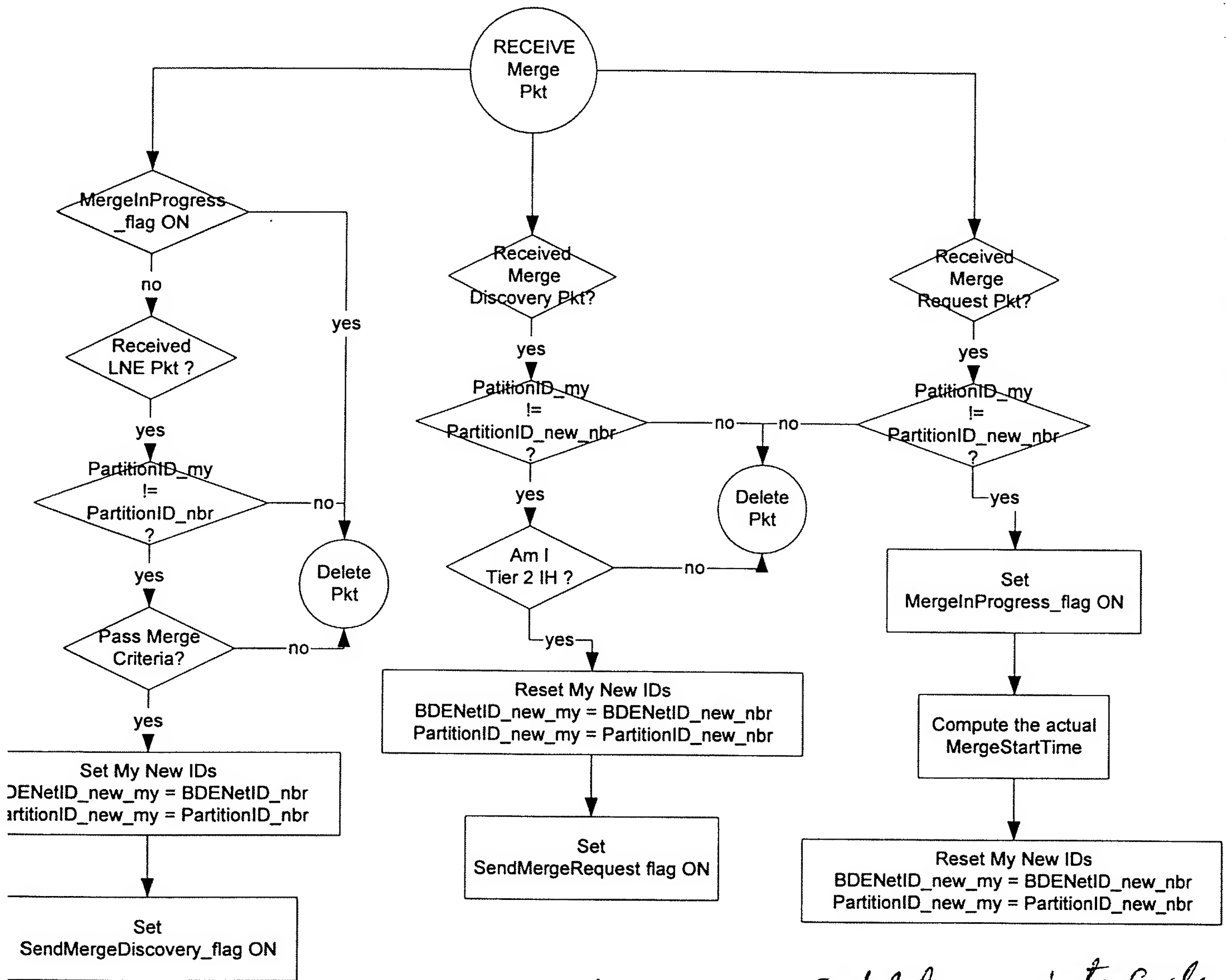

Merge Criteria
BDENetID_my = BDENetID_nbr
PartitionID_my = PartitionID_nbr
NetSize_my < NetSize_nbr

$\lambda' =$ actual pkt arrival rate

duty cycle

$$= \lambda \frac{\text{Interval}}{\text{modulo} + \text{Interval} + \text{Ran}/2} = \lambda \delta$$

$$= \lambda_i N \delta$$

$$P_s = 1 - e^{-2\lambda'\tau} \qquad e^{-2\lambda'\tau} = 1 - P_s$$

$$-2\lambda'\tau = \log_e(1-P_s) \qquad \lambda' = \frac{1}{2\tau} \log_e\left(\frac{1}{1-P_s}\right)$$

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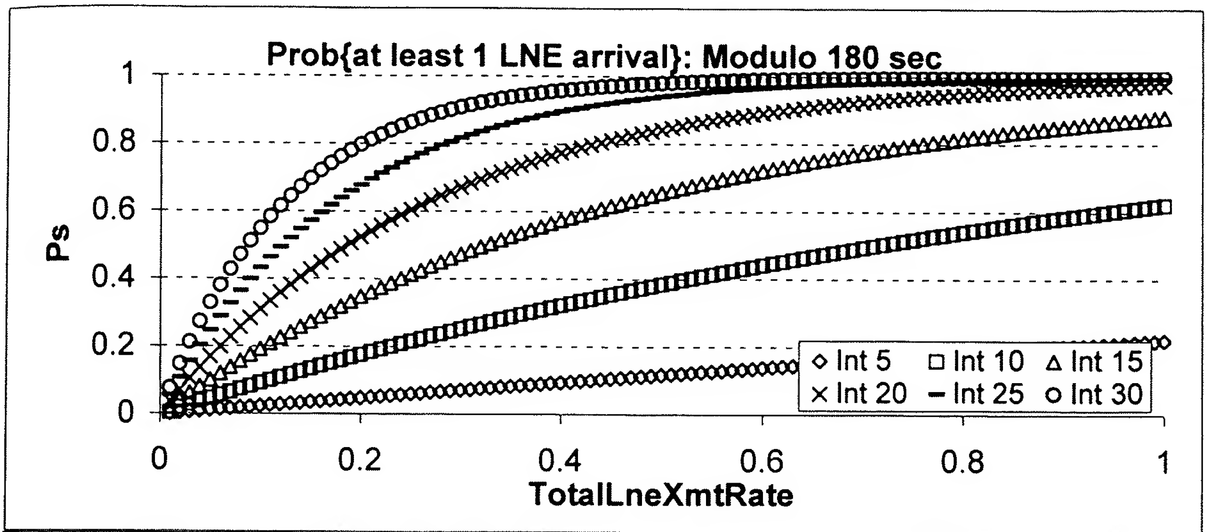

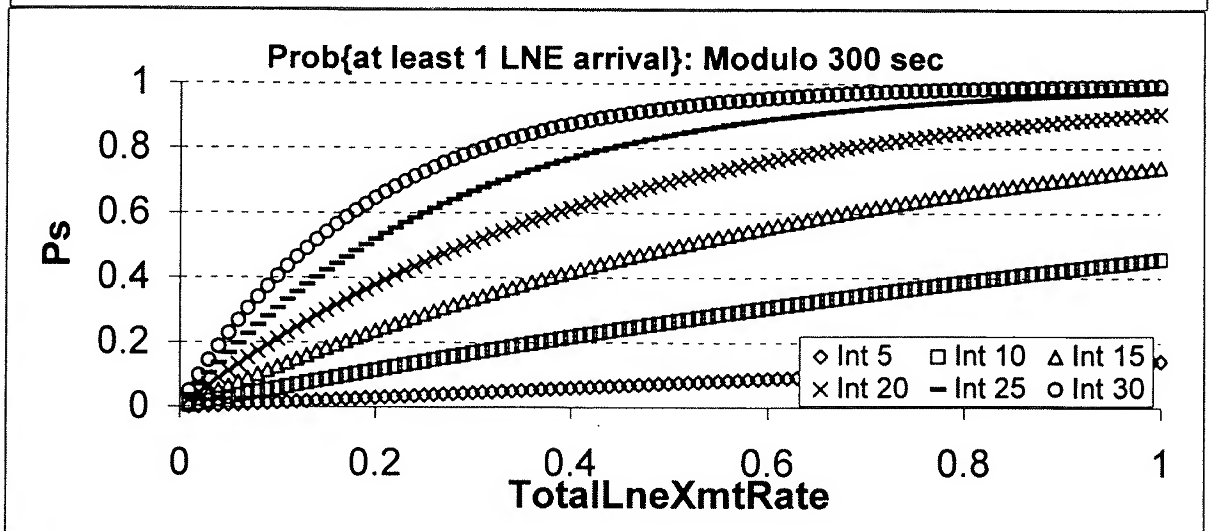

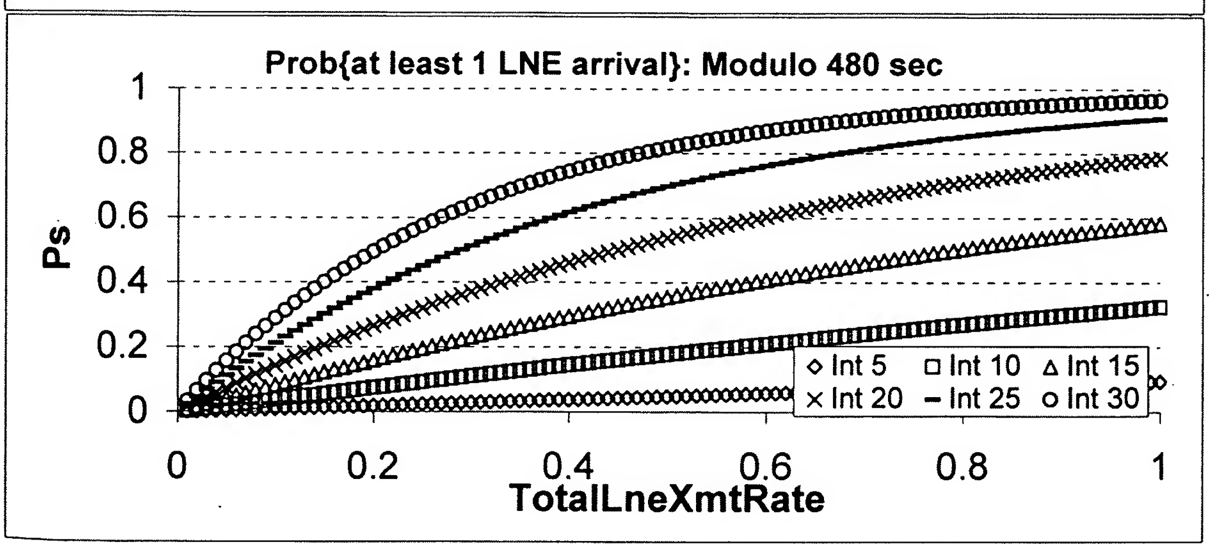

$\lambda = \lambda_i \times N$

duty cycle $= \frac{In}{Mod + In}$

$\boxed{\lambda_i = \frac{1}{N \times \delta}}$

$\lambda_i N \delta = \frac{1}{2\tau}$

$\lambda \delta = \frac{1}{2\tau}$

λ_i

$\delta = \frac{\tau}{\tau + D}$

$\lambda \delta \tau = l_0$

density $= l_0$

$\delta \tau = \frac{1}{\lambda} l_0$

where $\delta = \frac{\tau}{\tau +}$

$t_n = t_{n-1}$

RECORDED BY cj DATE Sept 17 '02

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$$K) = \frac{(\lambda\tau)^K e^{-\lambda\tau}}{K!}$$

b{at least 1 Lne Pkt arrive within Interval} $\triangleq \cancel{P_s} = 1 - e^{-\lambda\tau}$

terval = Lne listening Interval (or Lne Search Period) = τ

arch Period = $T_{mod} + \tau + \text{random}(\Delta T)' = \left(T_{mod} + \frac{\Delta T}{2} + \tau\right)_{average}$

sity $\triangleq$ ~~# Lne~~ # of LNE's in τ $= \tau\lambda$

= total LNE Xmt Rate in neighbor BTE Nets for merge

$= N\lambda_i$; N = # of node in merge Nets

$\triangleq$ actual Lne Rate in τ

$$= \lambda' \frac{\tau}{T_{mod} + \frac{\Delta T}{2} + \tau} = \lambda' \delta \ : \ \delta = \text{duty Cycle} = \frac{\tau}{T_{mod} + \frac{\Delta T}{2} + \tau}$$

$$P_s = 1 - e^{-\lambda\tau} \qquad \lambda\tau = \log_e\left(\frac{1}{1-P_s}\right) \qquad \lambda'\delta\tau = \log_e \frac{1}{1-P_s}$$

$$\lambda' = \frac{1}{\delta\tau} \log_e \frac{1}{1-P_s} = \frac{1}{\frac{\tau^2}{\boxed{T_{mod} + \frac{\Delta T}{2}} + \tau}} \log_e \frac{1}{1-P_s}$$

C

T

$$\lambda' = \frac{T + \tau}{\tau^2} C \qquad \lambda'\tau^2 - C\tau - CT = 0 \qquad \frac{\tau}{T+\tau} = \delta$$

$$\tau = \frac{C \pm \sqrt{C^2 + 4\lambda' CT}}{2\lambda'}$$

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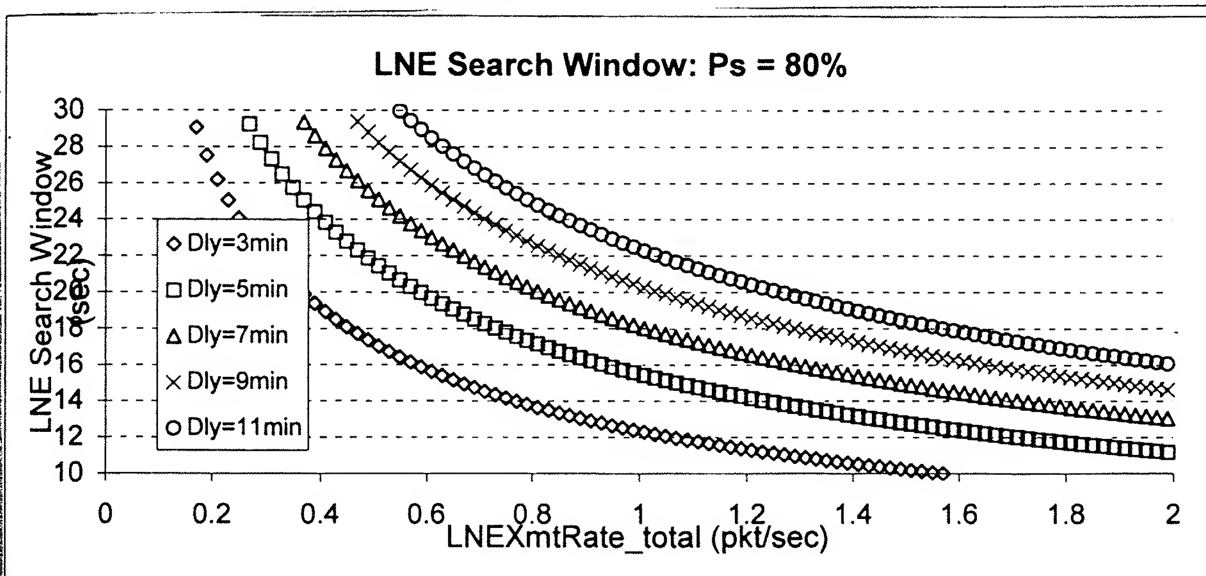

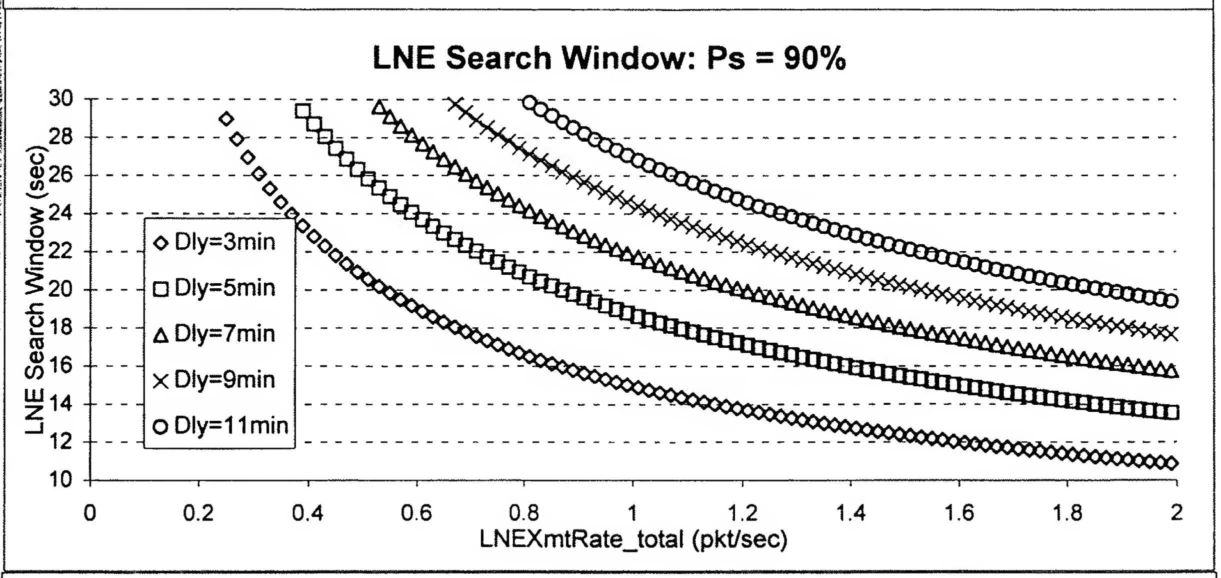

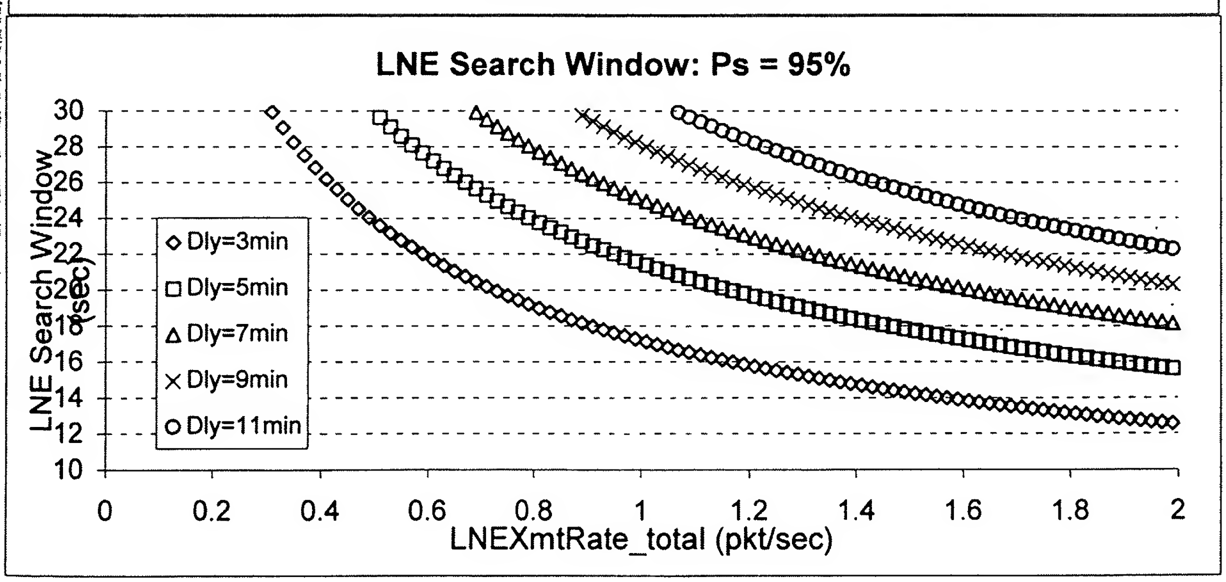

Estimat
Given b
Ps, Mod

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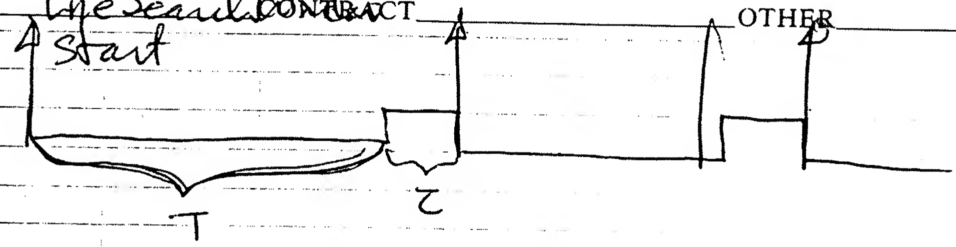

$N >$ max # of nodes : Doesn't want to merge
then T = max : stop to ~~open~~ Search Lne Search window

N= 6 → N=50
N=2 → N=50

- After merge wait T before re-merge
- network size & traffic intensity ?

Tier-2 Island Head controls T & τ etc

$$\frac{\tau}{T+\tau} = 1 - P_m \doteq \text{Prob}\{\text{message completion is required}\}$$

$$P_m = 1 - \frac{\tau}{T+\tau} = \frac{T}{T+\tau} \quad \text{given to Data}$$

$$P_s = 1 - e^{\lambda' \tau} = 1 - e^{\lambda \cdot}$$

$$\boxed{\begin{array}{l} \text{4 Variable} \\ \lambda, \tau, T_{delay}, P_s, \cancel{\ldots} \\ 1 \text{ eq} \quad \max \dfrac{\lambda \tau^2}{T_{delay} + \tau} \end{array}}$$

$$t_i = t_{i-1} + \text{ran}(T_{ran})$$

$$T_{ran} = R * \frac{N_{active}}{N_{max}} * F_{load} \qquad \sim \max\left\{\frac{\lambda \tau^2}{T_{delay}}\right\}$$

$$F_{load} = S_{offset} + S_{width} * m/(n+1)$$

$$e^{-\lambda\tau} = 1 - P_s$$

$$\lambda \tau = \log \frac{1}{1-P_s}$$

$$\lambda' =$$

$$\lambda_{max} = \frac{1}{\tau_{max}} \log \frac{1}{1-P_s}$$

$$T_{delay} = T_{priority} + T_{fix} + \text{ran}(T_{ran})$$

$$T_{ran} = f(F_{load})$$

BY C. Yoon DATE Oct 1 '02

D & UNDERSTOOD DATE 10/1/02

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EXHIBIT B

Attachment #1

SECTION G -- INVENTION DISCLOSURE

AUTOMATIC SWITCH OF TIME-OF-DAY SYNCHRONIZATION AND MERGE PROTOCOL AND APPARATUS

1. SUMMARY

Due to the severe timing constraints imposed by tactical wireless ad-hoc network, radios must establish a common network time before they can start to communicate. This is accomplished by Time-Of-Day (TOD) synchronization. Existing tactical radios, such as NTDR (Near Term Data Radio) system, built by ITT [1], can operate with two different TOD algorithms. The selection is based on a parameter in the pre-defined radio configuration. The normal TOD mode is GPS based TOD, in which network TOD is slaved to GPS time. The Brigade Time Head (BTH) based TOD is a secondary mode when GPS is not available. BTH based TOD synchronization means that network TOD is started by a single master (Brigade Time Head) radio. Time is then averaged across all participants in the network. If a radio network is started in the BTH mode, the network remains operating solely in this BTH mode. While operating as a BTH network, GPS configured radios will ignore GPS signals. No solution exists to move a BTH network, towards a GPS based network once the two time references differ by greater than one epoch in the existing NTDR TOD algorithm. If radios are configured for GPS based TOD, it is required that at least one radio is deployed with local GPS and the network operates solely as a GPS based network (as long as GPS is available). If GPS signals are lost the network will move to a BTH mode of operation. Once a radio is in the network, it stops looking for alternate timing sources; it only exchanges current net time with other nodes.

Futhermore, in a BTH based network, a radio will become operational only if it is in range of the network started by the BTH master. This means that nodes that are out of range of this network must remain off-line until connectivity is provided back to the main network. The existing NTDR TOD protocol does not allow merging of different timed based networks, even if they are close geographically and are within RF range.

This invention proposes a new TOD synchronization protocol allowing automatic detection and re-synchronization between GPS based and BTH based TOD networks. In addition, this service adds additional overall network improvements by allowing for multiple BTH masters. These additional masters will allow isolated radio nodes to

C. J. Yoon P. Walsh Witness 1: J. Protopapas Witness 2: C. Chan

operate as a small network until there is connectivity to the rest of the network. Once connectivity is established the two networks will merge. This flexible merge throughout the deployment will make the tactical wireless ad-hoc network much more robust and efficient under the mobile and volatile communication conditions.

2. DESCRIPTION OF THE OPERATION OF PRIOR DEVICES

2.1 TOD Synchronization In Commercial Ad-Hoc Networks

Recently introduced commercial wireless devices employ clock synchronization techniques for their operation in WPAN (Wireless Personal Area Networks) and WLAN (Wireless Local Area) Networks. Bluetooth devices [2] designed to support low bandwidth and short distance (< 10 m) wireless connections are an example of WPAN devices. Bluetooth specifies the protocols to be used by different handheld computing devices in order to communicate and exchange data. For timing purposes, Bluetooth specifies a master/slave clock synchronization mechanism allowing synchronization between neighbors being one-hop away from each other.

The IEEE 802.11 WLAN standard [3] specifies two different approaches for time synchronization: (1) one for infrastructure-based networks and (2) one for independent networks. For the infrastructure-based networks, IEEE 802.11 provides a master/slave clock synchronization mechanism. A special fixed node, the access point (AP), is used as a master, and all other nodes slave to this master. In an independent network, a mobile node transmits a beacon message, repeating on a beacon period. Each receiving node updates its clock with the value in the received beacon message if the received value is greater than its current local time. If the received value is less than the local time, the received value is discarded. No TOD merge algorithm is applied to amend among different TOD networks.

2.2 TOD Synchronization In Tactical Ad-Hoc Networks

Tactical radios such as the NTDR system, employing one receiver and one transmitter (1R/1T), tunes to the reservation channel whenever they are not involved in a message transaction. Since NTDR nodes can not monitor the reservation channel during a message transaction, timing messages could be lost. In new tactical radios, such ITT's SUO radio [4], to correct for this problem one auxiliary receiver is added to provide for two receivers in the radio (2R/1T). When the transceiver of SUO is used for a message transition, the auxiliary receiver switches to monitor the reservation continuously. The extra receiver, employed in the SUO system, requires additional hardware/software, a capability not available in NTDR.

C. J. Yoon | P. Walsh | Witness 1: J. Protopapas | Witness 2: C. Chan

2.2.1 NTDR TOD Protocol

NTDR TRANSEC can operate from two different TOD sources. The selection is based on a parameter in the radio configuration. The normal TOD mode is GPS based TOD. BTH based TOD is optional or provides a fall back capability if the GPS fails.

In GPS based TOD mode, network TOD is slaved to GPS time. A network member may receive GPS directly or receive a TOD message update from another radio (or node). Radios not receiving GPS signals are slaved to radios receiving GPS signals. To start a network, at least one of the radios in the network must be receiving GPS signal. If GPS signal is lost, across the whole network for a time period, network members then switch to the BTH based TOD algorithm. If a radio begins to receive GPS signal after switching to BTH mode, the GPS signal will be ignored and the radio will remain operating in the BTH mode.

In BTH based TOD, the network TOD is generated from the average TOD received from all radios during each pre-defined interval. One radio in the network is pre-designated to be the Brigade Time Head Master by the radio configuration. This is the only radio that can bring up a network. Once the network is up, new members join the network by getting TOD through Cold Start (CS) and Late Net Entry (LNE) messages. Because the master station is only used to start the network, should the master station disappear, this would no effect on the net. Splintered nets can join together only if their network TODs are within 80% of the TOD epoch.

In the current protocol only nodes without a selected timing source search for CS and LNE messages. Once these messages are received the node proceeds to make a timing source selection from the information in these messages. When a node is in the In-net mode of operation it will periodically transmit CS & LNE messages to bring in other nodes that are unaffiliated. Nodes that are operating in the "in net" state will not listen for other CS or LNE messages. These nodes are then unaware that other network(s) may exist operating with a time offset from their network.

2.2.2 SUO TOD Protocol

The TOD synchronization scheme of the NTDR system has been modified to meet the extra constraints of the SUO requirements: extreme mobile, volatile, power, and bandwidth limited operational conditions. The basic functionality of CS, LNE and In-Net modes of the NTDR system are similar to "Isolated", "In Sync", and "Associated" modes employed in the SUO system (2R/1T and 2R/2T). One of the key features of the SUO TOD synchronization scheme is that a roaming node with local GPS can synchronize

with the existing (non-GPS based) net time, immediately and slowly pull the net time toward the GPS based time. This so-called "flywheel" algorithm has been submitted for a patent [5].

3.0 Detailed Description Of NTDR TOD Synchronization

3.1 Description Of NTDR GPS TOD Synchronization

Figure 1 presents the flow diagram of the GPS based network process. Cold start (CS) messages allow "Isolated" nodes to join the network. Isolated nodes can be offset in TOD by large deltas from the "In-Net" TOD. When an "Isolated" node receives any CS message, the local clock is updated with the neighbor's net time and the node sets its status to "In-Sync". The Isolated node waits to receive additional LNE messages to further correct its time, before it changes to the "In-Net" status. If a node has a local GPS and has not received a CS message, it declares its status as "In-Net" and starts to send CS, LNE and TOD messages for a pre-defined WaitInNetTime (TBD sec) period. These messages are sent out at an accelerated rate, so that many nodes can join the network during this initial TOD operation. The GPS net time is updated in "In-Net" if GPS is available. If not, the TOD message contains zeros and is ignored. In the network, cluster heads transmits CS and LNE messages at a faster rate than cluster members.

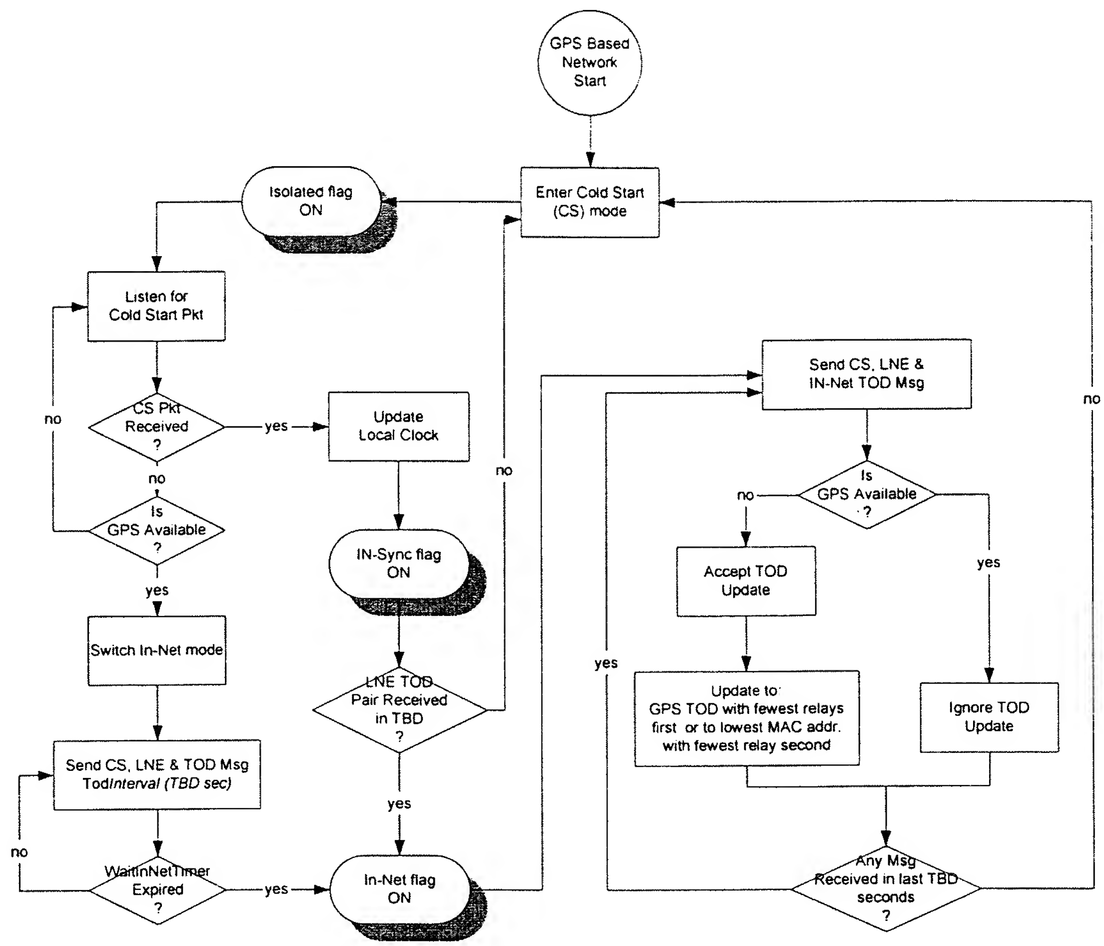

Figure 1. Flow Diagram of GPS Based Network Process

3.2 Description Of NTDR BTH TOD Synchronization

Figures 2 and 3 present the flow diagram of BTH based network process. When an LNE message is received at the "Isolated" node, as shown in Figure 2, a node replaces its local clock with the received time and become "In-Sync". If an "In-Sync" message is received before the InSyncTime is expired, then this node sets its state to" In-Net" and proceeds to the TOD maintenance procedures. If it does not get the "In-Sync" before the timer expires the node changes back to the "Isolated" status.

If an LNE message is not received and a radio is configured as BTH master clock, then, it sends out a BDE beacon to inform other radios that it is the master radio. The other non BTH master radios remain silent until they hear the BDE beacon message. Upon hearing this message, each radio sends out a BDE beacon acknowledgement (ACK) message

indicating that it is listening. The master hears the ACK, then, it starts a WaitBeaconAckTime to allow time for other radios to get turned on. After this WaitBeaconAckTime timer is expired, the master radio sends out multiple CS, LNE, and In-net messages. The BTH master sends one CS, one LNE, and one In-Net TOD message every InSyncXmtInterval for InSyncXmtDuration. After the InSyncXmtDuration interval, the master radio switches to normal "In-Net" operation. Until a radio is in "In-Net" operation, no data traffic is passed on a network except TOD update messages.

Once a radio is in the "In-Net" status, it broadcasts CS and LNE TOD messages at a rate depending on its cluster head or cluster member status, as shown in Figure 3. In-Net TOD updates are sent in the Link-Layer Header of all over the air (OTA) messages. A radio in "In-Net" status for BTH mode updates the local clock to the average of all TOD received in the last AverageNetTime period. If it does not received any message in last CheckNetThreshold, then it changes to the "Isolated" state and tries again to join the existing net.

C. J. Yoon	P. Walsh	Witness 1: J. Protopapas	Witness 2: C. Chan

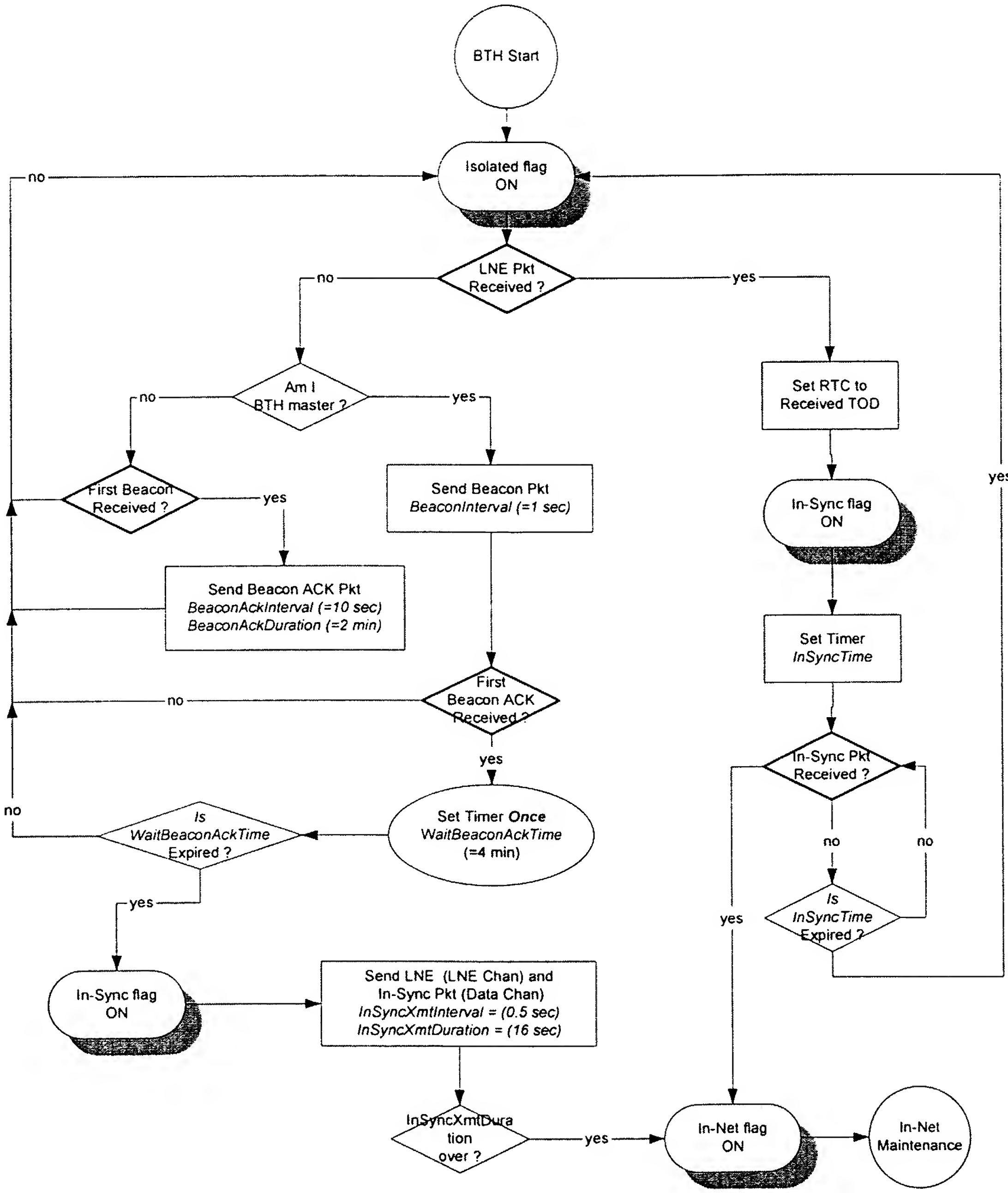

Figure 2. Flow Diagram of BTH Based Network Process – Isolated and In-Sync Status

C. J. Yoon | P. Walsh | Witness 1: J. Protopapas | Witness 2: C. Chan

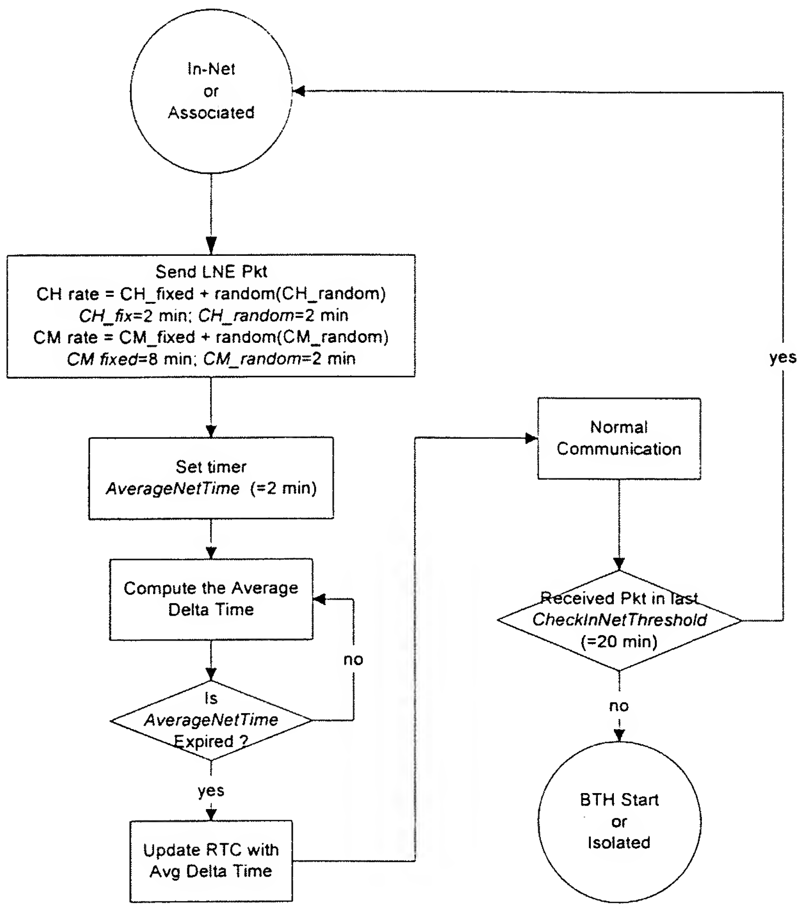

Figure 3. Flow Diagram of BTH Based Network Process – Maintain TOD Network in I-Net Status.

4. SHORTCOMINGS OF PRIOR DEVICES

The following describes drawbacks encountered when using existing TOD algorithms.

- Radio's deployed and configured for GPS based TOD, require at least one radio to acquire GPS to start the network. Failure of at least one radio to acquire GPS prevents the deployed network from forming.

- Radio's deployed and configured for BTH based TOD, require the master radio to start the network. Failure of the master radio to turn-on or to be available to the current network prevents the deployed network from forming.

- Radios not in direct contact with the current network will not start up. This could leave a large section of the network off when complete connectivity to the BTH is not available.

- When a BTH network fragments for longer than a maximum network separation time, the network will permanently fragment and have no way to remerge.

- There exists no merge mechanism in the existing approaches to combine a BTH based network with other BTH network(s) or GPS based network(s).

- There exists no mechanism in the existing approaches to move a network operating in BTH based TOD network to a GPS based TOD network.

- LNE epoch periods are quantized to six-minute increments because the TOD stamped at the link layer header is not the actual TOD time when the over-the-air message is sent. This large LNE epoch period causes slower TOD synchronization.

5. HOW THIS INVENTION OVERCOMES SHORTCOMINGS OF PRIOR DEVICES

Our invention allows a node to check for conditions in its geographic location and decide which way to start up the network. A node will check for an existing network, then GPS or master BTH status. If none of these conditions exist, the node will proceed to start the network. This isolated startup was not allowed previously, because without the merge function nodes would become permanently segregate from other nodes in the network. With the merge capability the various sections of the network can start when they are ready and merge when connectivity can be established.

That is our invention allows nodes to look, periodically, for other networks, and thereby discovering each other. Once the networks discoverer each other, a central control node will make decisions on how to merge the two networks. Each network sends out TOD messages to collect unaffiliated nodes. The affiliated node will now, periodically, look for these messages and identify other networks within range of itself. The nodes finding other networks will inform the central control node that other networks have been found. The central control node will use the information from its members to determine what connectivity exists between the two networks and what merge decisions need to be made. A key to this invention is that this search for other nets is optimized to limit impact on the overall network performance. The design uses network occupancy as a factor in the search algorithm. The larger the percentage of the network in a segment/fragment the lesser the time allocated to searching for other networks. These capabilities are enabled

through inter-node status information exchanges provided by the invented TOD protocol. This new TOD status information, such as network id, number of active members, merge in progress, are used to help in the merge process. Decisions are made to determine the most effective merge process among multiple networks. Smaller networks are responsible to search for larger networks. As a result, the larger networks have little or no degradation in performance.

6. DETAILED DESCRIPTION OF THIS INVENTION

Two new concepts are invented to improve the existing TOD protocols:

- TOD mode switch at initialization
- Merge Algorithm

6.1 TOD Mode Switch At Initialization

In Prior Art, a node will try to go operational in the TOD mode programmed in its configuration. However, under certain conditions nodes would not have the appropriate connectivity to go operational. In this invention, such conditions are analyzed and new decisions are added to allow nodes to come into operation with other local nodes. The reason that these selections were not available before was because when two or more nodes synchronized together they would be permanently isolated from the rest of the network. The new merge function allows these nodes to go operational and eventually merge when the nodes come in contact with the other nodes in the network. Local nodes operating in GPS mode will not require any changes. When nodes start up without GPS and there is no existing BTH network available to them, they will associate with other nodes and the lowest MAC addressed radio will start the network after a network search delay. The search delay is used to allow the node to find an operational network if one is available. This automatic BTH selection in a area will allow nodes to start up in diverse geographic or isolated areas without waiting for the network to be completely connected.

Figure 4 presents a flow diagram that shows how the currently deployed (or configured) mode can switch to another mode automatically, if the network can not be formed in a pre-defined period. When a node is deployed with a GPS based network and "isolated", it tries to synchronize with the existing net time, which is the GPS based time. If the nodes fail to form the network in a pre-defined time (WaitGpsBasedTime), then the node switches its mode to BTH based network mode. This node listens for a CS message and sets its local clock time with TOD information in the received CS message to synchronize with the net immediately. If the node receives any CS message with GPS or BTH timing the node will take this time from it's neighbors. If no CS messages are received, the node configured for BTH mode and it finds other unaffiliated node(s), it will changes it's BTH

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mode to master and try to form a network. Once the network is formed, the node's status is set to "In-Net" and the node maintains the net time, as described in the next section.

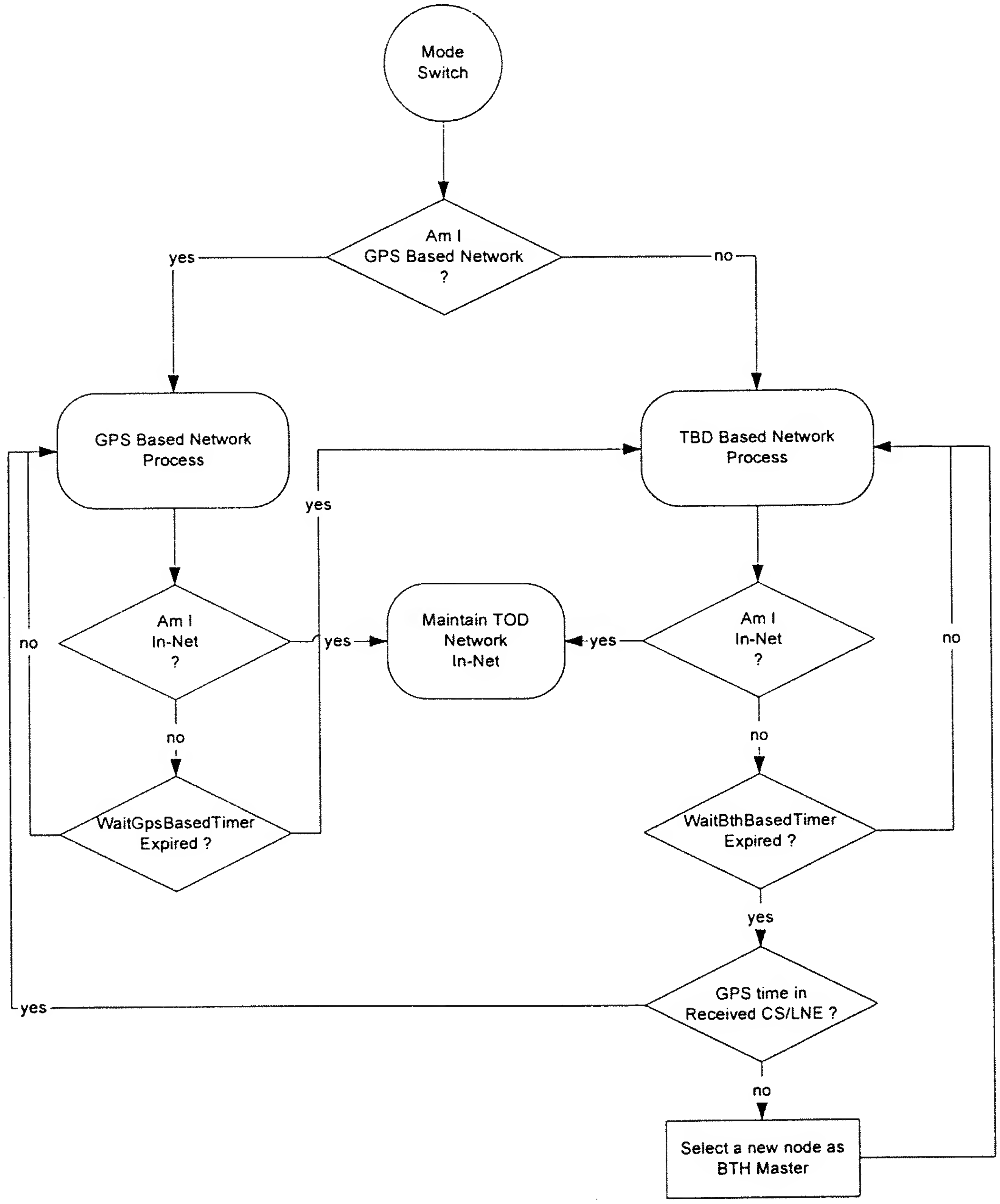

Figure 4. TOD Mode Switch At Initialization

6.2 TOD Merge Algorithm

When networks are operating in BTH based network mode, there are some instances where geographically separated groups in the network need to provide service before the whole network is deployed. In these instances the groups will start up in their area and operate till the rest of the network deploys. The problem is that in current art, networks operating in BTH based network mode, that are greater than one epoch off, were not able to merge. To regroup these networks a new BTH merge operation is required. This will require nodes in a network to periodically scan for other networks in their area. Once a network is detected, the smaller network will join the larger network in most situations. When any member of a BTH based network hears a TOD merge message from one or more members of another network, it can initiate the merge process. This process supports GPS networks as well as BTH networks. The merge algorithm has several parts, the first being the active nodes searching for other networks. All networks will transmit CS beacons so that nodes in other nets can receive these beacons and determine that different TOD networks exist. The second part of the algorithm is once new networks are discovered, decisions as to who/how networks are to merge will be made.

Figures 5 and 6 present the flow diagram of the proposed merge algorithm in TOD transmit and receive functions. The merge algorithm must be processed after a node has entered the "In-Net" state. The shaded blocks in Figure 5 represent the additional functionality that needs to be added to the conventional NTDR TOD synchronization algorithm in order to transmit the merge messages. CS messages contain the conventional TOD data plus new merge information (BDE net ID and partition ID) to be used by "Unaffiliated" nodes or other TOD networks. The following merge TOD information is added to conventional CS messages:

- BDE Net ID
- Partition ID
- Size of Current Network
- Designated BDE Net ID
- Designated Partition ID

6.2.1 Merge Transmit Algorithm

In Figure 5 user data has priority over CS messages. The detail derivation of merge parameters (formula 1 and formula 2) are described in Appendix A. CS transmit rates of cluster head and cluster members are re-defined in formula 1 for CS message to be successful at nodes in other networks. As mentioned before, a radio must alternate the receiver operation frequently from receiving the normal communication to listening for CS messages from neighboring networks. The time the CS window is opened to search for other networks (defined by formula 2) is adjusted by trade-offs defined in Appendix A between the overall performance and the efficiency of the merge process.

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The Transmit function is dependent upon certain information from the receiver section and the network. The receiver will detect a CS from another network and save that status. Also the Tier 2 control node will be informed of any detection's of other networks. The Tier 2 control node, in response to these network detection's will then set/change control states for the network. These state changes control the transmit and receive algorithm for the merge functions.

The transmitter will send a CS packet out periodically in accordance with a settable timer. The timer values change depending on the node's operational state of Cluster Member (CM) or Cluster Head (CH). The message rates are adjusted to help accelerate the receiver discovery process. The receiver CS window timing and the CS transmit timing are tuned in appendix A to minimize the discovery time versus network bandwidth used in the search. The transmitter's CS message will define the network ID, the tier 2 control node, and the size of the network. This information is used by each network to determine net identities and who should merge to whom. The smaller networks are encouraged to merge with larger networks.

When the tier 2 head decides that the network needs to merge, it sets the network TOD states in the message to tell the nodes what states the node should now operate in. The transmitter will advertise these states as part of the TOD merge process. The network will start the merge process at the merge start time. This merge start time is set by the tier 2 controller to allow for distribution to the entire network. This is so that all nodes will merge simultaneously. The ID of the network that the nodes are to merge with is distributed with this merge command. The nodes in the merging network will change their time to the network time of the new network. The nodes will need to re-establish network associations when merging into the new network.

6.2.2 Merge Receive Algorithm

The receiver in Figure 6 allocates the channel usage between user data and the CS channel. The receiver will receive In-net messages and other TOD control messages from its local network on this data channel. The CS channel is used to hear TOD advertisements from all networks in range of this receiver. Upon receiving a CS message from another network, the receiver will send a message to the tier 2 control node about the new network discovery. The merge algorithm calculates the percentage of time that the receiver spends on searching the CS channel for TOD messages of other networks. The time allotted for the search is reversely proportional to the size of my "current" network to the total network size. The larger my network the less time that is allotted for the search. The smaller networks would have the maximum time allotted to discover the larger networks. This puts the pressure on smaller networks to search and merge with larger networks.

When the new TOD merge messages are received, the incoming neighbor's merge TOD message is checked if my partition ID is different from the neighbor's designated partition ID. If the ID's are different then the messages are passed to the tier 2 control node (MergeDiscovery and MergeRequest).

While operating "In net" the TOD algorithm will function as in the previous design. The clocks will be synchronized to the GPS time, if available, or averaged with all neighbors in the BTH mode of operation.

6.2.3 Merge Decision Algorithm

When a tier 2 control node receives a message that a receiver received a CS message from another network, it checks if this network was "seen" before. If not, the tier 2 node starts a merge timer. When this timer expires the tier 2 control node will check and see if there are other networks discovered. The decision on what network should merge to another is made in the following sequence. Does one of the networks have GPS? If so, this would be the first selection. Does there exist a larger network than myself? If so, then this would cause this network to merge to the larger network. If the tier 2 node decides to do a merge, it will tell all nodes that a merge is in progress and the merge time would be distributed. Once a merge decision has been made the process will continue until the merge operation is complete. The merging network will send a message to the network that it is merging too, so that the network will stay operational till the merge is complete.

If a tier 2 control node hears from another network that a merge is requested, this network will acknowledge the merge request and disable other merges until this merge is complete.

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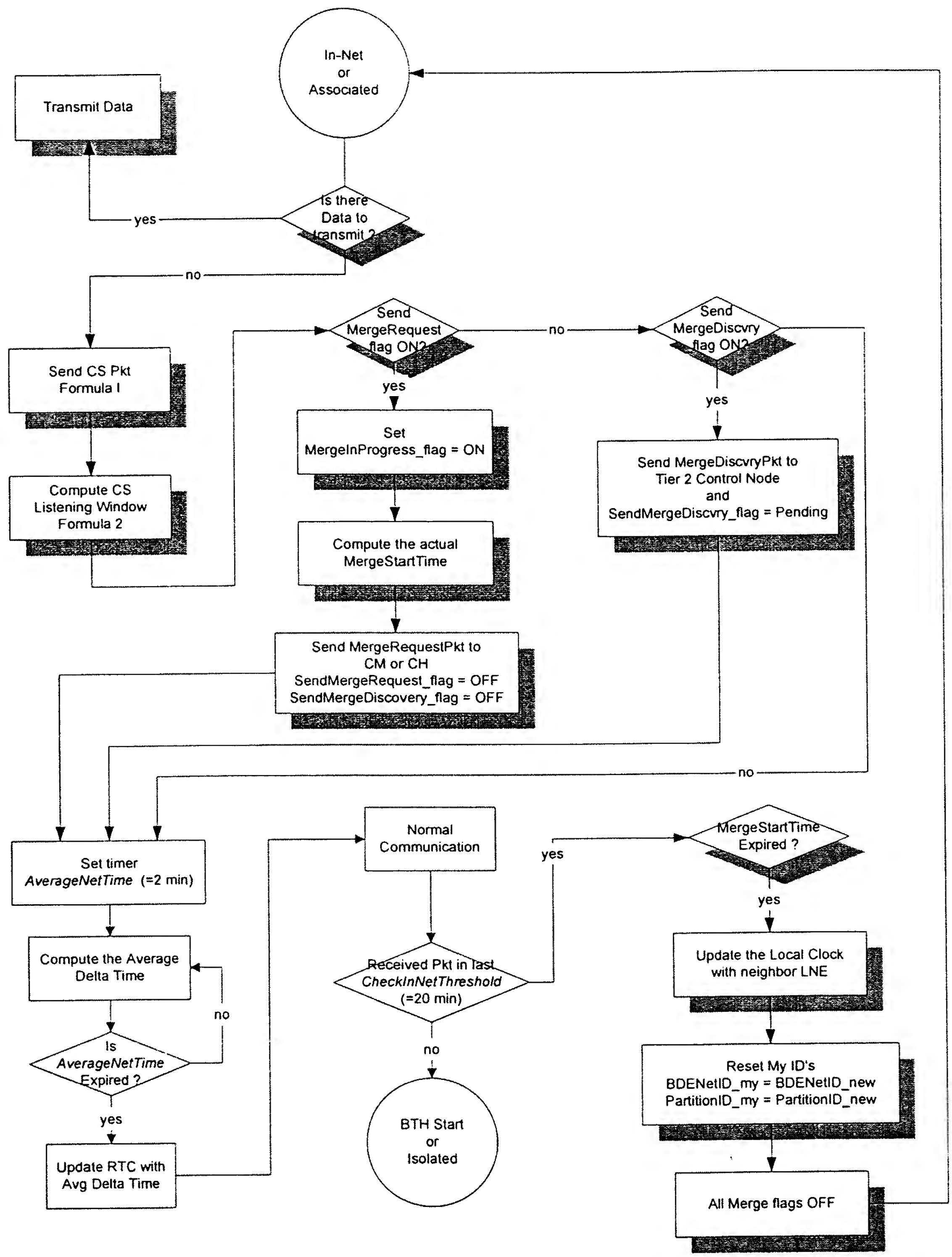

Figure 5. Flow Diagram of Merge Message Transmit Algorithm

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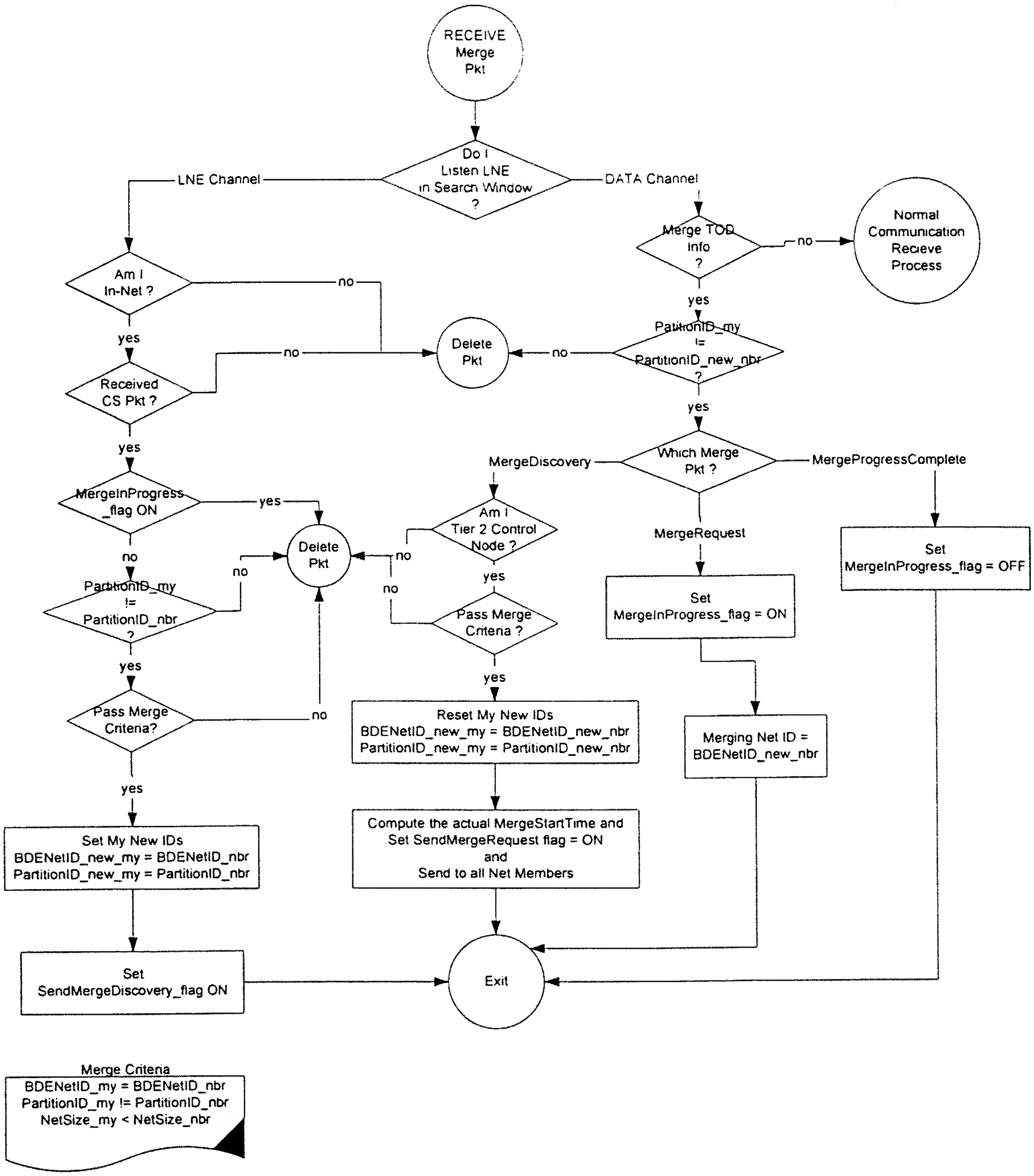

Figure 6. Flow Diagram of Merge Message Receive Algorithm

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7. LIST OF POSSIBLE APPLICATIONS

While the primary application of the invention described in this disclosure is tactical (ground-based) ad-hoc wireless networks, the algorithm is equally applicable to military ad-hoc wireless networks in general. That is, wireless networks involving airborne, ship-based, as well as mixed ground-based/airborne/ship-based network configurations.

Furthermore, the invented algorithm applies to commercial ad-hoc WLAN networks, which are generally more stable than the tactical networks. For the so-called infrastructure-based networks, IEEE 802.11 provides a master/slave clock synchronization mechanism. A special fixed node, the access point (AP), is used as a master. In an independent network, a mobile node transmits a beacon message, choosing a beacon period. Each receiving node synchronizes or merges its clock with the value in the received LNE message if the synchronization or merge algorithm, proposed in this disclosure is used.

APPENDIX A: DERIVATION OF PARAMETERS OF MERGE ALGORITHM

A.1 Reliability of LNE Message

As mentioned in previous section 6, the LNE transmit rate of cluster head is faster than that of cluster members. But we assume that the aggregate LNE transmit rate by all nodes in a TOD network has a total amount of λ messages per second. We also assume that the LNE message is generated at random pattern in a net and each message arrives randomly during the LNE search interval (τ). The probability of at least one LNE received (defined P_s) in a given LNE search interval (τ) is expressed by

$$Ps = 1 - \exp(-\lambda' \tau) \qquad (1)$$

where λ' is the actual LNE random arrival rate at the receiver. P_u is the probability of un-delibered LNE message.

The randomly transmitted LNE message of total rate (λ) is only received if the receiver is ready to hear by opening the LNE search interval (τ). The starting time of LNE search (T_{delay}) is randomized by

$$T_{delay} = t_{fix} + random(t_{ran}) \qquad (2)$$

where t_{fix} is the fixed term and t_{ran} is the random part.

Thus the actual LNE arrival rate (λ') during LNE search interval (τ) in equation (1) is re-written by

$$\lambda' = \lambda * (\tau / (T_{delay} + \tau)) \qquad (3)$$

To maximize the probability P_s, the following condition must be achieved for TOD merge algorithm:

$$\begin{aligned} &Maximize\{\lambda * \tau^2 / (T_{delay} + \tau)\} \\ &\xrightarrow[T_{delay} >> \tau]{} Maximize\{\lambda * \tau^2 / T_{delay}\} \end{aligned} \qquad (4)$$

The larger values of τ and λ are selected, the better probability of P_s at the expense of loss (or drop) of normal data, as expected. Notice that the change of τ has quardratic impact in equation (4). Also the faster channel access for LNE search, the better performance for TOD merge. The maximum result in equation (4) depends on three independent variables of the LNE transmit rate (λ), LNE search interval (τ) and LNE search delay (T_{delay}).

Given the probability (P_s = 80 %) and various values of T_{delay}, the LNE search interval (τ) versus total LNE transmit rate (λ) is plotted in Figure A-1.

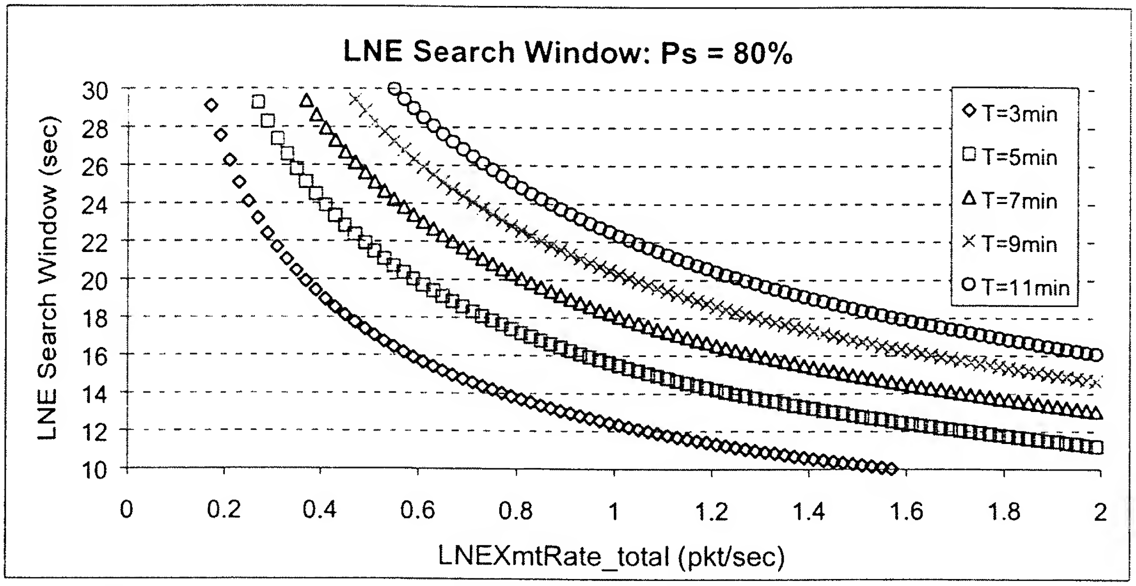

Figure A-1. Analysis of the Performance for receiving LNE Message Within LNE Search Window.

A.2 LNE Merge Information

Computation of proper LNE transmit rate (λ), length of LNE search interval (τ) and the random delay (T_{delay}) requires a prudent decision to consider the overall network performance and the reliable LNE reception to merge. After all, this selection (or formula) is the key to the effectiveness of 1R/1T radio's merge operation. And new formulas are proposed to compute optimum values of λ, τ, and T_{delay} in the following section.

Because tier-2 island head (IH) has overall information such as network sizes and traffic intensities in TOD network (BTH and/or GPS based) under tier-2 island, tier-2 IH decides which net has higher merge priority over others. Currently the merge priority solely depends on the TOD network size. The network size is to be the number of active nodes in the network and should not include nodes that will operate as spares in standby mode. Tier-2 IH has information of the total number of nodes under its tier (say N_{total}). The merge priority is quantized as shown in Table A-1 and the TOD messages are transmitted with the specified rate in network. The percentage of network size (ρ) is defined by

$$\rho = N_{active} / N_{total} \tag{5}$$

where N_{active} = active number of nodes in TOD network.

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N_{total} = total number of nodes in tier-2 island head.

Table A-1. Calculation of the merge priority

Percentage of Network Sizes	Bit Pattern
0.0	0 0 0 0
$0.0 < \rho <= 0.1$	0 0 0 1
$0.1 < \rho <= 0.2$	0 0 1 0
$0.2 < \rho <= 0.3$	0 0 1 1
$0.3 < \rho <= 0.4$	0 1 0 0
$0.4 < \rho <= 0.5$	0 1 0 1
$0.5 < \rho <= 0.6$	0 1 1 0
$0.6 < \rho <= 0.7$	0 1 1 1
$0.7 < \rho <= 0.8$	1 0 0 0
$0.8 < \rho <= 0.9$	1 0 0 1
$0.9 < \rho <= 1$	1 0 1 0

Tier-2 IH sends the merge priority to each network by adding to link layer header. Once the network size (ρ) is received, optimum values of λ, τ, and T_{delay} are computed dynamically by local nets.

Figure A-2 presents the TOD merge priority transmitted by the tier-2 island head to TOD network(s). BTH 1 network (small network) may merge to BTH 2 (medium network) first if it receives LNE message from BTH 2 first, rather BTH 3 (large network). To prevent the unnecessary multiple merges, tier 2 IH can decide which net merges with whom. Once a network has successfully merged, this new (and larger) network can not merge again until a pre-defined merge pacing delay has expired. This gives the other networks a fair opportunity to merge. As shown in equation (4), three variables (λ, τ, and T_{delay}) are independent each other to get the optimum result. But the selection of optimum value of τ is more critical impact (quadratic) over that of λ. Because the LNE search delay (T_{delay}) is much longer than the duration of τ and depends on the system performance, we need to investigate the trade-off study between the TOD synchronization and performance, prudently.

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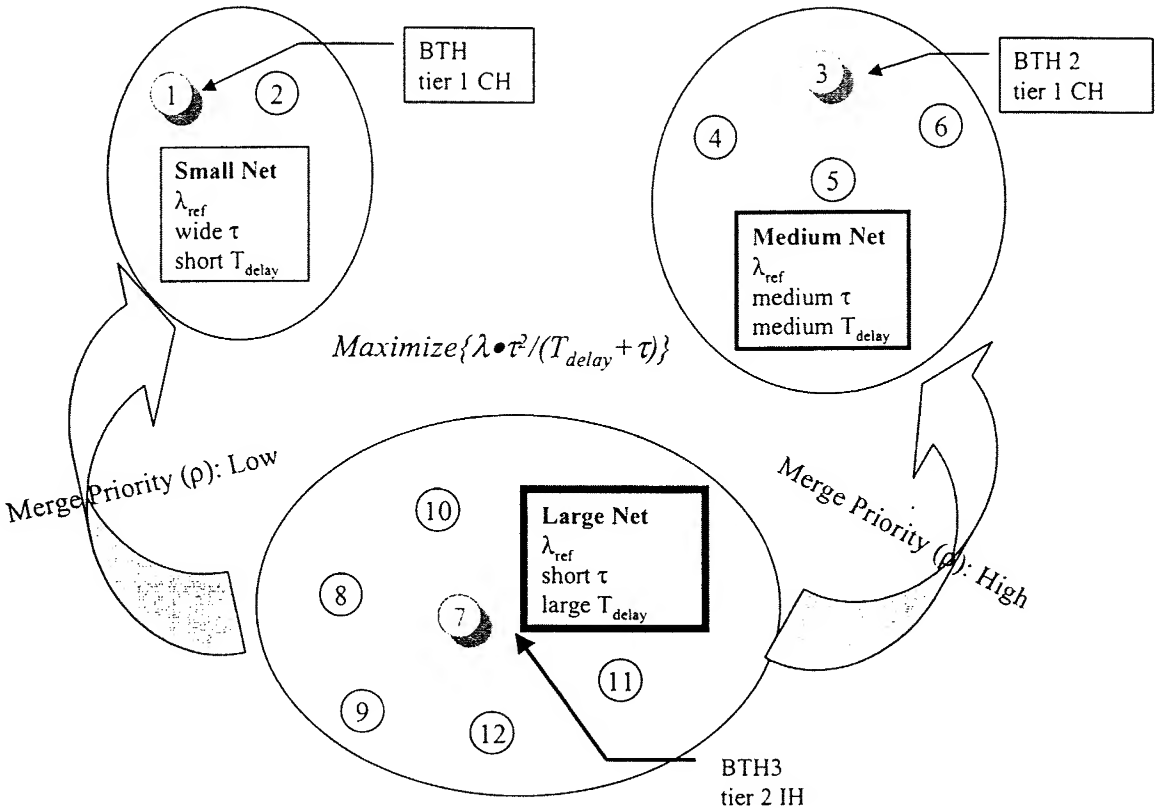

Figure A-2. Merge TOD Parameters.

A-3 LNE Transmit Algorithm – Formula 1

A node will transmit LNE signals at a relatively low rate. However, since all nodes of large networks will be issuing LNE messages independently, an "Isolated" node or smaller networks will quickly detect a LNE signal, despite the fact that individual nodes are issuing these messages at a lower rate. The LNE transmit rate (λ) depends on the cluster status, if it is cluster head (CH) or cluster member (CM), and is defined by the pre-defined rate (named λ_{ref}):

$$\begin{aligned} \lambda_{CH} &= CH_{fix} + random(CH_{ran}); \\ \lambda_{CM} &= CM_{fix} + random(CM_{ran}) \end{aligned} \qquad (6)$$

where

CH_{fix} = pre-defined fixed part of cluster head transmit rate (=2 min)
CH_{ran} = pre-defined random part of cluster head transmit rate (=2 min)
CM_{fix} = pre-defined fixed part of cluster member transmit rate (=8 min)
CM_{ran} = pre-defined random part of cluster member transmit rate (=2 min)

When the network size (ρ) is small, the larger LNE search interval (τ) is desired for the smaller network to merge with the larger network(s). Therefore, the network size (ρ) must be included in computing the optimum value of λ and τ:

$$\begin{aligned} \lambda &\propto f(\rho * \lambda_{ref}) \\ \tau &\propto f(\tau_{ref} / \rho) \end{aligned} \tag{7}$$

where λ_{ref} = pre-defined reference value of λ
τ_{ref} = pre-defined reference value of interval τ

Table A-2 lists the LNE transmit rate (λ) and the LNE search interval (τ). When data is ready to transmit, LNE messages are deleted so that the normal data has a priority over LNE messages. The LNE transmit rate (λ) and the LNE search interval (τ) can be clipped so when the network size (ρ) is greater than a pre-defined value (ρ_{max}), these values stay at λ_{ref} and τ_{ref}.

Table A-2. Calculation of λ and τ.

Percentage of Network Sizes	rate λ	interval τ
0.0	0	0
$0.0 < \rho <= 0.1$	$0.1 * \lambda_{ref}$	$\tau_{ref}/0.1$
$0.1 < \rho <= 0.2$	$0.2 * \lambda_{ref}$	$\tau_{ref}/0.2$
$0.2 < \rho <= 0.3$	$0.3 * \lambda_{ref}$	$\tau_{ref}/0.3$
$0.3 < \rho <= 0.4$	$0.4 * \lambda_{ref}$	$\tau_{ref}/0.4$
$0.4 < \rho <= 0.5$	$0.5 * \lambda_{ref}$	$\tau_{ref}/0.5$
$0.5 < \rho <= 0.6$	$0.6 * \lambda_{ref}$	$\tau_{ref}/0.6$
$0.6 < \rho <= 0.7$	$0.7 * \lambda_{ref}$	$\tau_{ref}/0.7$
$0.7 < \rho <= 0.8$	$0.8 * \lambda_{ref}$	$\tau_{ref}/0.8$
$0.8 < \rho <= 0.9$	$0.9 * \lambda_{ref}$	$\tau_{ref}/0.9$
$0.9 < \rho <= 1.0$	λ_{ref}	τ_{ref}

A.4 LNE Search Delay Algorithm – Formula 2

The following factors must be included to compute the proper values of T_{delay}:

- When traffic intensity is decreased, then a node can allocate more to search LNE message, vice-versa.
- Some nodes could be silent and the only active nodes (N_{active}) are counted by network size.
- The larger network size, the longer T_{delay} is selected.

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- After a node finishes a merge, it waits a pre-defined time before it tries to merge again to ensure all cluster members merge.
- If a network size is larger than the pre-defined ρ_{max} in network, then it stops to hear LNE message by setting T_{delay} infinite.

Considering the above factors, new LNE search delay (LSD) timer is proposed to ensure that each node has an equal chance of accessing the channel to search LNE message. Upon expiration of T_{delay} timer, node starts to listen LNE messages in τ seconds. The continuous LNE search delay (LSD) is recalculated for next channel access for LNE search:

$$\begin{aligned} T_{delay} &= T_{priority} + T_{fix} + random(T_{ran}) \\ T_{ran} &= \kappa * (N_{active} / N_{\max}) * F_{load} \\ T_{\min} &< T_{ran} < T_{\max} \end{aligned} \tag{8}$$

where

$T_{priority}$ = time delay computed by priority level of network from tier 2 IH, as listed in Table A-3.
T_{fix} = pre-defined fixed part of LSD computation to wait for merge pacing delay.
T_{ran} = random part of LSD computation.
κ = scale factor to control the random part.
T_{min} = pre-defined minimum value to bound T_{ran}.
T_{max} = pre-defined minimum value to bound T_{ran}.

For tactical internet division below (TIDB) channel access [6], the net access delay (NAD) formula is employed efficiently to access channel. Computation of load factor, F_{load}, is modified so that NTDR network characteristic is utilized for TOD merge conditions. The load factor, F_{load}, can be computed by:

$$\begin{aligned} F_{load} &= S_{offset} + Integer\{S_{width} * [\delta_i / \sqrt{\sum_{j=1}^{N_{active}} \delta_j^2}]\} \\ S_{offset} &= Integer\{\rho * Max_{factor}\} \\ S_{width} &= Max_{factor} - S_{offset} \end{aligned} \tag{9}$$

where

δ_i = duty cycle of "not busy" channel at node i.
Max_{factor} = pre-defined value of maximum value of load factor F_{load}.

Node operating in a NTDR channel access protocol attempts to maintain an accurate record of the usage of the data channel. Each node tracks the period of time that each data channel is in use along with the identity of the nodes using the channel. The Holdoff

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Delay (η) is the time that the channel is busy with data transmission. This Holdoff Delay (η), along with other information, are stored in a net allocation vector (NAV). The duty cycle (δ_i) is computed with the Holdoff Delay (η_i) at i-th node.

$$\delta_i = 1 - \frac{1}{T} \int_t^{t+T} \eta_i \times dt \qquad (10)$$

where T is the average time interval for computing the duty cycle.

The additional time delay, $T_{priority}$, is computed by multiplying the network size (ρ) to the pre-defined the reference time ($T_{rpriority\_ref}$), as listed in Table A-3.

Table A-3. Calculation of the Time Delay of $T_{priority}$.

Percentage of Network Sizes	$T_{priority}$
0.0	0
$0.0 < \rho <= 0.1$	$0.1 * T_{rpriority\_ref}$
$0.1 < \rho <= 0.2$	$0.2 * T_{rpriority\_ref}$
$0.2 < \rho <= 0.3$	$0.3 * T_{rpriority\_ref}$
$0.3 < \rho <= 0.4$	$0.4 * T_{rpriority\_ref}$
$0.4 < \rho <= 0.5$	$0.5 * T_{rpriority\_ref}$
$0.5 < \rho <= 0.6$	$0.6 * T_{rpriority\_ref}$
$0.6 < \rho <= 0.7$	$0.7 * T_{rpriority\_ref}$
$0.7 < \rho <= 0.8$	$0.8 * T_{rpriority\_ref}$
$0.8 < \rho <= 0.9$	$0.9 * T_{rpriority\_ref}$
$0.9 < \rho <= 1.0$	$T_{rpriority\_ref}$

After the LNE search delay (T_{delay}) is expired and a node waits until the channel is not busy, then the receiver switches from receiving data to listening the LNE during the LNE search interval (τ). If we assume that the network size (ρ) is greater that 70 % (ρ_{max}), then T_{delay} becomes infinite so that the network devote all resources to normal communication, that is, not allowed to merge any more. Table A-4 lists the example of λ, τ, $T_{priority}$ for ρ_{max} to be 70 %.

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Table A-4. Calculation of λ, τ and T with $\rho_{max} = 70\%$

Percentage of Network Sizes	rate λ	interval τ	$T_{priority}$
0.0	0	0	∞
$0.0 < \rho <= 0.1$	$0.1 * \lambda_{ref}$	$\tau_{ref}/0.1$	$0.1 * T_{priority\_ref}$
$0.1 < \rho <= 0.2$	$0.2 * \lambda_{ref}$	$\tau_{ref}/0.2$	$0.2 * T_{priority\_ref}$
$0.2 < \rho <= 0.3$	$0.3 * \lambda_{ref}$	$\tau_{ref}/0.3$	$0.3 * T_{priority\_ref}$
$0.3 < \rho <= 0.4$	$0.4 * \lambda_{ref}$	$\tau_{ref}/0.4$	$0.4 * T_{priority\_ref}$
$0.4 < \rho <= 0.5$	$0.5 * \lambda_{ref}$	$\tau_{ref}/0.5$	$0.5 * T_{priority\_ref}$
$0.5 < \rho <= 0.6$	$0.6 * \lambda_{ref}$	$\tau_{ref}/0.6$	$0.6 * T_{priority\_ref}$
$0.6 < \rho <= 0.7$	$0.7 * \lambda_{ref}$	$\tau_{ref}/0.7$	$0.7 * T_{priority\_ref}$
$\rho > 0.7$	λ_{ref}	τ_{ref}	$T_{priority\_ref}$